

CA1 HW1180 E54

CA1 HW 1180E54

Canada, DNH, EHD,

80-EHD-54

ASSESSING THE EFFECTIVENESS OF SMALL FILTRATION SYSTEMS
FOR POINT-OF-USE DISINFECTION OF DRINKING WATER
SUPPLIES, 1980.

santé et Bien-être social
Canada

CA1 HW1180 E54

Assessing the effectiveness of small filtration systems for point-of-use disinfection of drinking water supplies



Earth Sciences Library



Digitized by the Internet Archive
in 2025 with funding from
University of Toronto

<https://archive.org/details/31761056887854>

ASSESSING THE EFFECTIVENESS OF SMALL FILTRATION SYSTEMS FOR
POINT-OF-USE DISINFECTION OF DRINKING WATER SUPPLIES

Environmental Health Directorate
Health Protection Branch

Published by Authority of the Minister
of National Health and Welfare

January 1980

COPIES OF THIS REPORT
CAN BE OBTAINED FROM:

Information Directorate
Department of National Health
and Welfare,
Brooke Claxton Building,
OTTAWA K1A 0K9

ACKNOWLEDGEMENTS

This report describes studies conducted by the Ontario Research Foundation (ORF) under contract to the Monitoring and Criteria Division of the Environmental Health Directorate. Acknowledgement is given to Drs. R. Tobin and V.C. Armstrong who were primarily responsible for preparing the report. The valuable assistance provided by Messrs. D. Smith and A. Horton (ORF) in the preparation of the report is greatly appreciated.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	vi
BACKGROUND	vii
PART I	
Development of a Test Procedure for Bactericidal Filtration Systems	1
INTRODUCTION	3
MATERIALS AND METHODS	
Test Equipment	4
Selection of Test Filters	4
Filter Cleaning Procedure	5
Calibration of Feed Pumps	5
Timing Cycles	6
Flow Measurements	6
Test Organisms	6
Test Waters	7
Microbiological Analysis	8
Measurement of Silver Concentrations in Water Samples	10
Test Protocol	10
RESULTS AND DISCUSSION	
Filter Performance	14
CONCLUSIONS	17
PART II	
An Examination of the Efficacy of Bactericidal Filter Units Representative of Currently Available Models	19
INTRODUCTION	21

MATERIALS AND METHODS

Test Equipment	22
Test Filters	22
Filter Cleaning Procedure	22
Calibration of Feed Pumps	23
Timing Cycles	23
Flow Measurements	24
Test Organisms	24
Test Waters - Chemical Composition	25
Microbiological Analysis	25
Measurement of Silver Concentrations in Water Samples	25
Test Protocol	25

RESULTS AND DISCUSSION

Filter Performance	26
--------------------------	----

CONCLUSIONS AND RECOMMENDATIONS	28
---------------------------------------	----

REFERENCES	30
------------------	----

TABLES	31
--------------	----

FIGURES	41
---------------	----

ABSTRACT

A test protocol was refined and applied to the testing of commercially available point-of-use water filtration devices for which bactericidal or bacterial removal claims are made. The report is divided into two sections.

In Part I, experiments to compare the use of an Escherichia coli culture (ATCC 11229) as a challenge organism with the use of total coliform organisms from a fresh sewage source are described. After some initial difficulty with the variability of the E. coli in the test feed, counts were stabilized in the range of 1000-5000 coliforms/100 mL or higher. It was considered that, because of their ready availability, ease of handling, and increased physiological and genetic variability, the raw sewage organisms provided a more appropriate challenge for testing bactericidal and bacterial removal claims.

In Part II, procedures designed to assess the performances of two other brands of in-line devices and one hand-held unit are presented. Each in-line device was tested in triplicate and the hand-held model in duplicate according to regimes designed to simulate a lifetime of normal usage with contaminated water. The ceramic silver type unit employed in the protocol development phase served as a convenient control. The units containing a ceramic cartridge impregnated with metallic silver removed all coliform organisms in the 40-day test period and maintained the total plate counts at a low level, usually below 500/mL. The hand-held unit of similar construction tested in a manual mode, began to give erratic results after passage of about 18-22 L and could not be depended upon to provide water of an acceptable quality. The other model tested, which filtered water through activated carbon and contained no silver, was almost completely ineffective in reducing the bacterial challenge.

BACKGROUND

An increasing interest in drinking water quality has prompted manufacturers of water treatment equipment to develop a variety of devices for point-of-use (home) application. The purpose of these may be to further improve the quality of an already potable municipal supply and/or render drinkable a source of raw water. Few of the many devices available to the consumer have been adequately tested for performance, especially with respect to their ability to function satisfactorily over their recommended lifetimes. This has led to concern by a number of organizations including governments responsible for health protection over potential health hazards where raw water has been inadequately treated. In addition, claims made for certain systems may not have been substantiated by properly conducted tests thereby misleading the consumer. During 1976-1977 the Environmental Health Directorate of the Department of National Health and Welfare conducted a study to ascertain the types, and extent of use, of point-of-use water treatment devices (excluding water softeners), available to the Canadian consumer. In this study test protocols and/or evaluation criteria against which the efficacy of each type of unit might be assessed were tentatively outlined (1).

Point-of-use water treatment devices are designed to perform one or more of three general functions: (a) microbiological treatment (either disinfection of a raw water source or inhibition of growth of microbial populations present in treated supplies); (b) chemical removal; and (c) particulate removal. With regard to potential health hazards it is clear that ineffectiveness in systems intended for disinfecting raw water sources could result in the most serious and immediate consequences. With this in mind, the Environmental Health Directorate's program to evaluate water treatment devices focused initially on the refinement of test procedures for, and laboratory testing of, systems designed to eliminate or reduce the bacterial content of water.

A number of devices which are intended for use on raw or untreated water supplies incorporate silver as an antimicrobial agent. Although the bactericidal properties of silver have been demonstrated under carefully controlled conditions, its disinfecting action is dependent on such variables as temperature, pH, concentration of silver released to the water and the level of interfering species such as chlorides, phosphates, sulphides, dissolved oxygen and the contributors to water hardness. Most of the silver-containing "bactericidal" units which are available in Canada rely on a filtration step to remove bacteria; the filter may be impregnated

with silver to destroy the captive bacteria and prevent their growth through the filter medium. Systems employing such filters may be designed for counter-top or under-the-sink installation or may be portable hand-held units.

The purpose of this report is twofold:

- (a) to describe the refinement and evaluation of a possible procedure for testing the disinfecting ability of systems which employ filtration as the effective process, and
- (b) to present the results of tests conducted on bactericidal filtration units currently available to the Canadian consumer.

The units considered in this report were selected as representative of those in-line devices employing ceramic cartridges for filtration (2 brands), hand-operated portable units employing ceramic cartridges, and in-line activated carbon units for which bactericidal claims are made or implied. Omitted from the present investigation are systems employing the more sophisticated filtration processes such as reverse osmosis and ultrafiltration.

PART I

Development of a Test Procedure for Bactericidal Filtration Systems

INTRODUCTION

Filtration units designed to effect disinfection of a raw water source frequently contain silver as an inhibitor for microbial growth. A rigorous procedure for testing such units should therefore include an examination of the effect of varying water quality on the silver content of the treated water as well as on the viability of the challenge organism(s). The protocol tentatively proposed in the report, "Survey and Test Protocols for Point-of-Use Water Purifiers"(1), incorporated such provisions. Test waters were defined in terms of total dissolved solids (TDS), non-purgeable total organic carbon (NPTOC) content, turbidity, pH range and temperature. Adjustment of the pH and TDS at appropriate times during the accelerated life test sequence were proposed in order to create conditions under which silver release to the water should be facilitated and/or the possibility of bacterial overgrowth enhanced.

For the microbial challenge it was considered that use of either a stock E. coli (ATCC 11229) suspension or a mixed microbial population (including coliforms) obtained from raw sewage would provide an appropriate challenge for bactericidal filters. In either case a total coliform level from 1000 to 5000 organisms per 100 mL should be maintained throughout the test period, the rationale being that this range incorporates the maximum level of bacterial contamination that is treatable by conventional technology(2). Raw water contaminated beyond this range should not be used by an individual as a source of drinking water because of the inherent health risks.

In this part of the report the proposed protocol is examined for its suitability and the two microbial challenges described above compared in order to ascertain the most appropriate for a standardized procedure. In addition, the rigorous testing of the filter unit chosen for this exercise provide a convenient reference point for evaluating the performance of units as described in Part II of this report.

MATERIALS AND METHODS

Test Equipment

The test equipment employed (Figures 1 and 2) is based on a schematic for a test assembly for bacteriostatic type filters (i.e., filters intended for installation in an already potable supply system), supplied to the Water Quality Improvement Standards and Certification Council (WQISCC) by a U.S. manufacturer(1). The two manifolds, which can accommodate up to four test filters, employ dechlorinated water obtained from the municipal supply via a backflow preventer and activated carbon filter. Positive displacement pumps are used to inoculate a suspension of the challenge microorganism(s) into the flowing stream of dechlorinated water in the manifold upstream of the filters under test. In this way an inoculation at any desired challenge level may be fed to all the filters on the manifold under dynamic conditions.

Selection of Test Filters

It has been recommended(1) that at least three filters of the same type, but from three different batches, be investigated simultaneously. For the present comparative study therefore two sets of three units were employed. The model used (unit A) is a current production filter designed for in-line (counter-top or under-the-sink) use; standard units were obtained directly from the manufacturer. The design comprises a hollow cylindrical ceramic cartridge, impregnated with silver. The ceramic material is composed of a mixture of clays and diatomaceous earth of porous structure. Suspended particulates greater than 1 μm in diameter are retained on the outside of the cartridge. The cartridges tested incorporated optional activated carbon packings in the hollow core; these are intended to remove or reduce the organic content of the water or improve the organoleptic properties and are not required for the disinfection process. The cartridges were examined for obvious cracks or flaws prior to mounting in the test apparatus but were not checked for leaks by bubble pressure tests.

On the basis of a maximum daily demand of 30 L for drinking and culinary purposes and a "normal" silver residual ($\sim 20 \mu\text{g/L}$), the manufacturer suggests the cartridge's life expectancy to be at least two years.

The accelerated test program was designed to establish efficacy and life expectancy in a 40-day program assuming a flow rate of 4.5 L/min (1 Imp. gal/min). At a projected flow rate of 450 litres of water in 16 hours this period would be equivalent to about 1.6 years of filter use at an upper estimated withdrawal rate

of 30 L/day, or 2.5 years at a reduced rate of 20 L/day. Since low TDS and high TDS waters and a final high bacterial challenge were also to be used in the program it was felt that this period of testing would adequately cover the equivalent of 2 years normal household use.

Filter Cleaning Procedure

When flow rates decreased to approximately 500 mL/min, the filter units were disassembled and the ceramic surfaces of the filters cleaned in accordance with the manufacturer's instructions. A flow rate of approximately 500 mL/min was selected as the point for cleaning the filters since it was reasoned that a user would not be willing to wait more than 30 seconds to obtain a glass (200-250 mL) of water. A soft copper gauze provided with the filter for cleaning purposes was used to scrape the surface of the filters under a stream of tap water. This removed adhering deposits of a yellow/brown material which collected on the surface of the filter. These deposits appeared to be partially inorganic and organic in nature with the colour most probably due to iron and algae deposits. The flow rates were restored virtually to their original values by the cleaning procedure. Some ceramic material is abraded by the cleaning procedure and, after seven cleaning cycles during the course of processing about 6000 to 9000 L of water, the filters became noticeably reduced in diameter.

Calibration of Feed Pumps

The Neptune proportioning pumps used to add the bacterial challenges were first calibrated against zero head. The results for both pumps are shown in Table 1. A mid-point pump setting of 60 was selected for calibration under dynamic conditions of pressure and flow through the manifold to the filters. Flow from both pumps under flow conditions through the filters of 4.5 L/min was found to be the same (80 mL/min) at a setting of 60.

It should be noted that no attempt was made to proportion the feed rate as the volume of water per minute passed by the filters progressively decreased between cleaning cycles. The feed rate was virtually independent of volume and resulted in higher challenge numbers of microorganisms being fed to the filters as the flow through the manifold dropped. This was not felt to be a serious drawback to the test since both sets of filters were being run under the same conditions. It was thought that any attempt to modulate the feed to the flow rate would probably result in much greater errors and differences between the two sets.

Timing Cycles

The two sets of three-unit A filters were run under the same conditions except for bacterial challenge. The timing cycles were set to simulate normal household water consumption and to approach the lifetime expectancy of the units. Two 24-hour timer clocks were used to control the cycles; they were set to run 16 hours per day seven days per week with a normal "off" period of 8 hours overnight. The circuitry used for controlling the timers is shown schematically in Figure 2.

The timers were set so that water would flow through each unit for 3 minutes out of each half hour (i.e., 6 min/hour) during the 16-hour day. A total elapsed timer meter which recorded the running time for each manifold system was used as a monitor. The two systems were synchronized by minor adjustment to the "on-off" cycle timers to hold an average "on" time of 100 min/day for both systems. Individual daily variations at the extreme were 92 minutes to 108 minutes, with most daily cycles within the range 96 to 106 minutes. (Low TDS and high TDS tests were run only 8 hours, with a 16-hour stagnation period). These flow cycles resulted in the treatment of an average of about 9600 L per unit during the 40-day test period.

Flow Measurements

Flow measurements were made daily by collecting the volume delivered from each filter for exactly 30 s and recording as millilitres per minute. Although individual recording rotameters would have been a refinement, the additional costs involved and gain in accuracy in a long-term study such as the present 40-day period were not deemed worthwhile.

Test Organisms

(a) E. coli (ATCC 11229)

The culture, after several sub-transfers through liquid medium, was streaked on Tryptone Glucose Extract (TGE) agar. A loopful of inoculum from the TGE agar was grown for 48 hours on nutrient broth at 35°C for 48 hours. The suspension was centrifuged and washed with buffered water three times. An aliquot of the suspension was diluted in sterile buffered water to give an absorbance at 665 nm of approximately 0.21. One millilitre of this suspension was used to seed 60 litres of dechlorinated water in the reservoir. This procedure had to be modified after about the third day of testing by the addition of 1000 mL of filtered and autoclaved domestic raw sewage to the suspension of E. coli in the reservoir. This was required to protect the coliforms from rapid kill by residual combined chlorine in

the manifold. The stock suspension was kept refrigerated and the reservoir suspension replaced about every third day. Fresh stock was prepared weekly.

(b) Coliforms from Raw Sewage

Fresh domestic sewage was obtained from a sewage pumping station on the Ontario Research Foundation premises (Sheridan Park Research Community, Mississauga). The sewage was filtered through glass wool to remove gross suspended matter. A blended sample of 1000 mL was used to seed 60 L dechlorinated tap water in the reservoir to yield about 1000 to 5000 total coliforms/100 mL in the final dilution in the manifold.

Test Waters

(a) Chemical Analysis

A chemical analysis of the three types of water used in the study was performed. The samples for analysis were taken from the manifold and included the bacterial challenge.

Parameters	ORF Tap Water	Low TDS* Water		High TDS* Water	
		Run 1	Run 2	Run 1	Run 2
Total dissolved solids mg/L	218	109	97	940	850
Total organic carbon (TOC) mg/L	2.8	2.5	1.9	3.3	4.7
Total inorganic carbon mg/L	23.9	11.5	11.5	114	102
Chloride (Cl ⁻) mg/L	31	15	13	130	124
Sulphate (SO ₄ ⁻⁻) mg/L	29	15	17	116	90
Ammonia-N mg/L	0.15	<0.1	<0.1	0.12	<0.1
Total alkalinity } mg/L as CaCO ₃	95	50	65	270	260
Total hardness }	140	70	75	510	445
pH	7.1	6.0	6.0	8.3	8.1
Turbidity JTU	<1	<1	<1	<1	<1
Temperature °C	4.5	14	14	10	10

* TDS - Total dissolved solids

The low TDS water was obtained by diluting dechlorinated tap water 1:1 with distilled water, and the high TDS water by spiking dechlorinated tap water with sodium carbonate, magnesium sulphate and calcium chloride in approximately the same ratio of the anion content in the tap water to give a TDS content of 800 mg/L.

(b) Effect of Added Raw Sewage on Total Organic Carbon (TOC) Content

The total organic carbon (TOC) content of the dechlorinated tap water in the manifold was not measurably changed by the addition of 1 litre of raw sewage to the reservoir. This would also be expected from theoretical considerations as follows:

Filtered raw sewage TOC = ~ 100 mg/L

Dechlorinated tap water TOC = 1.8 mg/L to 2.8 mg/L

Since 1 litre of sewage was added to 60 litres of dechlorinated tap water, this would elevate the TOC of the reservoir water from, say 1.8 mg/L to $1.8 + \frac{100}{60} = 3.46$ mg/L, or 0.00346 mg/mL. At the lowest range of flow of water recorded in the manifold, with three filters connected, of ~1000 mL/min and a constant injection rate of 80 mL/min from the reservoir, TOC would be increased to only $1.8 \text{ mg/L} + (80 \times 0.00346) = 2.07$ mg/L.

Microbiological Analysis

(a) Sample Collection

Samples were collected in 1000 mL sterile flasks containing 1 mL of neutralizer for each 100 mL of sample collected. Microbiological analyses were performed immediately after sample collection.

(b) Neutralizer Solution

5% Sodium thioglycolate

7.3% Sodium thiosulphate

Sterilized by filtering through a 0.22 µm filter.

(c) Coliform Enumeration

The single step direct technique using membrane filters on Endo agar as described in "Standard Methods for the Examination of Water and Wastewater"(3) was used. Incubation was carried out at 35°C for 22-24 hours. Initially, 100 mL samples were examined for coliforms from filter effluents. (Duplicate samples were run and the mean coliforms counts per 100 mL recorded). Later in the program this volume was increased to 250 and 500 mL aliquots. Peptone water (1%) was used as rinse water for the filtration step.

(d) Standard Plate Counts

In the original procedure it was intended that standard plate counts would be carried out only on the influent and filtrates from filters where raw sewage was being used as seed(1). However, since the objective of the study was to compare the two types of challenges, plate counts were conducted for both the E. coli and raw sewage seeded filters. The membrane filter technique with filters placed on Tryptone Glucose Extract Agar (TGEA) and/or standard plate counts directly into TGEA were used, depending on the volume examined. Incubation was carried out at 35°C for 48 hours. Counts were recorded as plate counts per mL.

(e) Effectiveness of Neutralizer Solution

The following control tests were carried out to demonstrate that the neutralizer solution did not adversely affect recovery of E. coli; and that the neutralizer effectively stopped the reaction of silver on E. coli.

Aliquots of an E. coli (ATCC 11229) suspension, prepared from the input inoculum to the filters containing 810 organisms per mL by MF count and plate count, were diluted 1:10 with filtrate from one of the Unit A filters having a Ag⁺ concentration of 15 µg/L. One series of dilutions was neutralized at time zero, 30 min, 60 min, 120 min and 240 min with 1 mL of neutralizer solution. Replicate samples from this series and from matching unneutralized suspensions were run, using the MF coliform method for enumeration.

The results were as follows:

	<u>Zero</u>	<u>30 min</u>	<u>60 min</u>	<u>120 min</u>	<u>240 min</u>
Neutralized immediately (mean count/mL)	78	80	80	88	97
Neutralized at time indicated	78	63	ND	ND	ND

Measurement of Silver Concentrations in Water Samples

(a) Cleaning of Bottles

Polypropylene bottles (40 oz: Nalge) were soaked sequentially for 16 hr intervals with non-ionic detergent solution, 10% (v/v) aqueous ammonia solution and 10% (v/v) nitric acid solution. The bottles were rinsed well with deionized distilled water after each treatment and then rinsed with ethanol (distilled in glass) for drying at room temperature.

(b) Sample Preservation

High purity nitric acid (prepared by sub-boiling distillation) was pipetted (2 mL) into each bottle prior to collection of the sample. The solutions were stored in the dark at room temperature until analysis.

(c) Analytical Procedures

Samples were analyzed by flame (air/acetylene) atomic absorption spectrophotometry (AAS) or flameless atomization atomic absorption spectrophotometry (FAAS), using the wavelength 328.1 nm. The selection of technique depended on the respective range of concentrations in the groups of samples. In general, concentrations lower than 20 ppb ($\mu\text{g/L}$) were analyzed by FAAS. Where possible, the standard solutions for calibration were prepared in the same matrix as the samples, i.e., tap water, high total dissolved solids, etc.

Simultaneous background correction was used for all FAAS analyses. Contrary to previous data(1), multiple atomization peaks were not encountered in this study in the FAAS analysis of silver in tap water solutions.

Simultaneous background correction was used in the flame AAS of selected samples but was found to be unnecessary.

Test Protocol

The test protocol previously described(1) was used as the basis for the filter tests as follows:

<u>Day</u>	<u>Activity</u>	<u>General Chemical</u>	<u>Ag⁺ Analysis</u>	<u>Bac T Coliform</u>	<u>SPC</u>
1 Start up	- Condition units according to manufacturer's specs, set flow rates.				
	- Determine Blank values on effluents with dechlorinated tap water only as influent.			X	X
	- Begin regular on/off flow cycle with bacterial challenge.	X	X	X	X
2	- Determine Bac T and Ag ⁺ under dynamic flow conditions. Continue cycle with challenge.		X	X	X
3	- Continue cycle with challenge.				
4	- Bac T and Ag ⁺ after overnight stagnation period.		X	X	X
5	- Continue cycle.				
6	- Bac T and Ag ⁺ under dynamic conditions.		X	X	X
7	- Continue cycle.				
8	- Bac T and Ag ⁺		X	X	X
9	- Low TDS water + challenge under dynamic flow.	X	X	X	X
10	- Bac T and Ag ⁺ after overnight stagnation.		X	X	X
11	- High TDS water + challenge under dynamic conditions.	X	X	X	X
12	- Bac T and Ag ⁺ after overnight stagnation. Continue with regular cycle.		X	X	X
13	- Continue regular cycle.				
Sampling continued approx. every 2nd day, alternating sampling under dynamic and static (overnight) conditions.					

35	- Low TDS + challenge under dynamic flow.	X	X	X	X
36	- Bac T and Ag ⁺ after overnight stagnation. Continue regular challenge.		X	X	X
37	- High TDS water + challenge under dynamic conditions.	X	X	X	X
39	- High Bac T challenge, ~50 000 coliforms/100 mL. Sample under dynamic conditions. Continue with high bacterial challenge.		X	X	X
40	- Sample after overnight stagnation.	X	X	X	X

RESULTS AND DISCUSSION

In the following discussions the 3 units challenged with E. coli are designated as series "E" and those challenged with raw sewage bacteria as series "S".

During the first three days of testing it was found that, although present in the reservoir, E. coli (ATCC 11229) organism were not recovered in samples from the test manifold. The coliforms in the raw sewage challenge, on the other hand, were recovered in samples from the manifold. Tests using the N,N-diethyl-p-diphenylamine (DPD) chlorine test(3) on the dechlorinated tap water after the carbon filters indicated no free chlorine but an appreciable combined chlorine residual (~ 0.8 mg/L). Subsequent investigation showed that, while a chlorine residual could be removed readily by activated carbon, chlorine combined as chloramines was removed only slowly; at a flow rate of approximately 13.6 L/min, (3 gallons/min), removal of chloramines by carbon filters was incomplete.

In order to overcome this problem it was decided to try to protect the E. coli inoculum by adding 1000 mL of glass wool filtered, autoclaved raw sewage to the 60 L reservoir. This was the same amount of raw sewage (but not autoclaved) used for the "S" series challenge. The results of the addition of protective organics are obvious from day 4 onwards in Table 2. No further problems were encountered with die-off of coliforms in the manifold.

Some difficulty was experienced in obtaining counts within the desirable limits of 1000 to 5000 coliforms per 100 mL in the manifold. The variation was due mainly to the decline in flow rate through the filters and the constant volume pumping rate of the inoculum from the reservoir. However, omitting the deliberate final high challenge on day 40, the daily challenge from day 4 was within the range 1000 - 5000 coliforms/100 mL 14 times in 23 measurements for the "E" series, and 14 times (starting from day 3) in 24 measurements for the "S" series. Except for days 5 and 6 for the raw sewage challenge where the coliforms were lower than 1000/100 mL, all remaining coliform counts were above the 5000/100 mL level in both the "E" and "S" series. Some of these higher readings constituted a very high bacterial challenge (up to 30 000 coliforms/100 mL) and as a result it was decided that the final high challenge should be increased by a further decade to about 500 000 coliforms/100 mL to see if breakthrough occurred.

Standard plate counts were performed on the influents and effluents of both sets of filters. During the break-in period both sets of filters with no added

bacteria delivered a "sterile" effluent - below the level of detectability in 1000 mL. For the "E" series the standard plate count was somewhat higher than total coliform count. Counts carried out on the effluent directly from the carbon filter in the "E" series water line (i.e., before inoculation with the challenge seed in the manifold) indicated a standard plate count of about 3 organisms/100 mL at a flow rate of about 15 L/min and >300 per 100 mL under static conditions. Standard plate counts in the "E" series were thus expected to be higher than the coliform count. Similarly, the carbon filters in the "S" series would be expected to contribute to the input standard plate count but the proportion would be small in relation to the total bacteria from the sewage seed.

Filter Performance

(a) Coliforms

Only one confirmed coliform colony was recovered in all of the tests carried out on the effluents from the filters. This was on day 40 in the final high challenge (400 000 coliforms/100 mL) test in the raw sewage ("S") series. Non-sheen colonies were observed in some instances in the course of the 40-day test period in both "E" and "S" series growing on the membrane filters on the coliform selective medium (designated in Table 2 as ND*). Cultures of single colonies were taken from the membrane filters but failed to be confirmed as coliforms (i.e., no sheen or pink mucoid colonies) when subsequently cultured and streaked on Endo agar. Microscopic examination also indicated that these were not coliforms.

(b) Standard Plate Counts

Standard Plate Counts on the effluents from the filters in both "E" and "S" series were variable. Counts, where they did occur, were in most instances less than 3 per mL. In general, good control of standard plate count organisms was observed since periods of elevated counts (3 per mL) were followed by periods of low (<3 per 100 mL) or non-detectable counts in 100 mL samples. Despite the higher total count challenge in the "S" series with raw sewage, the plate counts in the effluents from the "S" series were similar to those in the "E" series. The inference is that only a very small proportion of the input organisms can pass through the filter and/or are resistant to silver ions. Those organisms which do pass through the filters in either case may be derived from the upstream carbon filter used for dechlorinating rather than from the raw sewage challenge.

Although standard plate counts were carried out at 35°C for 48 hours, it was observed that very slow-growing pigmented organisms tended to show up after 48 hours incubation. For this reason, in all subsequent studies the plates were read at 48 hours and again at 72 and 96 hours.

(c) Effects of Low TDS (total dissolved solids) and High TDS Water

The low TDS and high TDS tests had no adverse effects on coliform removal ability of the filters. The high TDS in the first trial (days 11-12) appeared to increase the number of standard plate count organisms in the filtrate. In the second test the low TDS and high TDS waters markedly increased the SPC. The reasons for this are not known but the filters in the second test (days 37-39) had just been cleaned and were, therefore, running at over twice the flow rate compared to the first test, during the dynamic portion of the test. It may be that bacteria were being washed off the inner activated charcoal core of the Unit A filters in the second test since on days 38 and 39 the standard plate counts on the effluents were greater than those on the influents.

(d) Silver Ion in the Effluent

Table 3 shows the results of silver analysis on the influent water and the individual effluents from the filters. Time of contact of the water with the filters was the main factor influencing silver levels. The samples taken after a period of stagnation are invariably higher than samples taken under dynamic flow conditions. The levels were, however, well within the 50 µg/L maximum acceptable concentration for drinking water(2), except for the final low TDS and high TDS test where levels up to 76 µg/L were found after a 16-hour stagnation period. This latter portion of the experiment was therefore repeated at a later date using the same filters to establish under what conditions elevated silver levels might be encountered in the effluent.

A low TDS water was prepared by blending 1 part dechlorinated tap water with 1 part distilled water. Samples were taken for silver analysis after 4 hours of running (dynamic samples) and after overnight (16 hours) stagnation (static samples) on the low TDS water. The results are shown in Table 4. The flow rates through the filters for the dynamic samples were as follows: E₁ 1000 mL/min, E₂ 600 mL/min, E₃ 1200 mL/min, S₁ 800 mL/min, S₂ 700 mL/min, S₃ 900 mL/min. The temperatures of the dynamic samples and the static samples were, respectively, 14°C and 22°C. These conditions are similar in all respects to those in the full 40-day test.

The chloride ion concentration of the low TDS water was 15 mg/L and the TOC 2.1 mg/L. It will be noted from Table 4 that the mean values for Ag^+ for the dynamic samples are similar to those shown in Table 3 for dechlorinated tap water runs. This is not too surprising since time of contact and temperature are probably the factors limiting the dissolution of silver during filtration. The static samples, although showing higher values for silver than the dynamic samples, were not quite as high as some of those recorded in the low TDS tests in the 40-day run.

Re-checks of the previous static low TDS samples from the 40-day run with high values (which had been preserved and stored in acid) were run and the values confirmed.

In order to further check static silver levels a re-run of the "E" series was carried out with low TDS water after the filters had been run for 24 hours on dechlorinated tap water, followed by 8 hours of low TDS water. Static samples were collected after 16 hours stagnation in the low TDS water. The results are shown in the lower portion of Table 4.

That values in excess of 50 $\mu\text{g/liter}$ of Ag^+ were not observed in these low TDS static tests may be attributable to: (a) the filters reaching the end of their useful life, (b) the period of standing in a dry condition after the 40-day run altering the conditions of saturation of Ag^+ ion in the carbon bed within the filter, (c) previous values $>50 \text{ ug/L}$ having resulted from a newly cleaned and abraded filter.

(e) Water Flow Rates

Table 5 shows the daily and cumulative flows for the six filters. Total cumulative flows ranged from a low of 6200 litres to just over 9000 litres in the 40-day period. This was less than the objective of approximately 18 000 litres. Nevertheless, 9000 litres would correspond to the equivalent of about 300 days of use at a high daily water demand of 30 L/day, and over 2 years of use at a more probable daily household usage rate of 12 litres per day. A greater volume of water could have been processed during the 40-day period by more frequent cleaning of the filters. This was not done because it would not simulate normal household use.

CONCLUSIONS

The use of a laboratory-cultured organism such as ATCC 11229 to challenge water treatment should help ensure that test conditions and procedures remain uniform and reproducible. Conversely, seeding the test water with raw sewage may be seen as preferable since the resulting microbiological characteristics of the test water resemble more closely those likely to be encountered under actual use conditions.

The results of the tests described in this part of the report indicate that either E. coli or indigenous coliforms in domestic raw sewage may be used as test organisms. Preference should be given to the raw sewage challenge since the washed laboratory cultures of E. coli are sensitive to rapid inactivation by residual combined chlorine in the present test method and must be protected by the addition of organic material such as autoclaved sewage. The presence of the small amounts of organic material in the raw sewage inoculum does not appear to adversely affect the bactericidal or removal efficiencies of silver filters.

The fact that all six of the cartridges examined produced effluent free from the indicator coliform organisms throughout the tests, even where levels greatly exceeded 5000 coliforms per 100 mL indicates the design of this type of filter can be extremely efficient. Only one confirmed coliform colony was found in the effluent from one filter in the last test when the coliform challenge was 400 000/100 mL. Control of standard plate count organisms in the filtered water, under normal challenge conditions, to 3 or less per millilitre was also achieved. Plate counts of up to 500/mL in drinking water are generally considered acceptable(2). Such units may therefore be deemed appropriate for use as controls in assessing the relative disinfecting abilities of other filter systems. (See Section II).

The silver content of the water was under the 50 µg/L maximum level recommended for drinking water under the normal dynamic and static conditions of the test protocol. Silver levels in samples taken under dynamic conditions with low TDS water were also in the range encountered in dechlorinated tap water runs. Levels above 50 µg/L were only encountered with low TDS water after long contact times. From these data it would appear therefore that excessive silver release should not be a problem with this kind of filter, except where a low TDS water is allowed to remain in contact with the filter medium for extended periods.

PART II

An Examination of the Efficacy of Bactericidal Filter Units Representative of Currently Available Models

INTRODUCTION

The basic criterion against which any water treatment system should be judged is that it produces water of a quality equal to, or preferably higher than, that defined by the maximum acceptable concentrations prescribed in the Guidelines for Canadian Drinking Water Quality(2). The primary objective of the study described in this part of the report was to establish the disinfecting ability of various filter designs currently available in Canada. Maximum acceptable concentrations established for microbiological parameters should therefore not be exceeded in the treated water. A number of filter devices incorporate silver as a growth inhibitor for organisms retained in the filter medium; silver levels in the effluents should be within the maximum acceptable concentration of 0.05 mg/L(2).

Three types of filters, representative of ceramic cartridges, portable hand-held units, and activated carbon cartridge units carrying bactericidal claims, were selected for testing. These three types typify units most commonly sold for bacterial removal by means of filtration. Omitted here are the more specialized and expensive types such as reverse osmosis units. In testing each type, one of the ceramic-silver cartridge units employed in the initial studies described in Part I of this report, and already shown to be effective, was used as a control. In this way it was hoped that a point of reference would be provided for successive tests and permit evaluation of a unit's performance under conditions deviating appreciably from the intended protocol. For example, failure of a given unit and a control because of an excessively high bacterial challenge would not necessarily result in condemnation of the unit under examination.

MATERIALS AND METHODS

Test Equipment

The test manifold system used was the same as that described in Part I of this report (Figures 1 and 2).

Test Filters

The design of the test manifold permits the simultaneous testing of up to 8 units. Two sets of three filters (B and C) designed for "in-line" use (and for which bactericidal claims were made or implied) were examined and may be described as follows:

1. Unit B employs a cylindrical ceramic cartridge, with silver finely distributed throughout the ceramic tube. The core of the cylinder is also filled with silver-impregnated quartz presumably to prevent penetration and growth of organisms on the outlet side of the filter.
2. Unit C comprises a charcoal depth-filter: From the design specifications of this model, it appeared that silver was not incorporated in the unit.

Three of each of the above units were mounted together, each set with a control (Units A_B and A_C) identical to the ones described in Part I; the operation of each group of 4 was controlled by a 24-hour timer.

3. Unit D is a hand-held portable version of Unit B; it is described as a pocket filter fitted with a hand-pump and is capable of providing about 4 L (1 gallon) of filtered water in 5 minutes.

Two portable Unit D filters were tested manually.

Filter Cleaning Procedure

(a) Unit A

The control unit on the Unit B filter test side of the manifold, A_B , was cleaned each day throughout the test. This was done in order to process the maximum volume possible in the 40-day test period. The filters were cleaned in accordance with the manufacturer's instructions. The control unit on the Unit C test side, A_C , was only cleaned seven times during the course of the 40-day test program when the volume dropped to less than 250 mL/min.

(b) Unit B

The surface of the candle is designed to be cleaned with a stiff bristle brush which is provided with each unit. With the brush method it was difficult to

clean the filter thoroughly. As the test progressed, the filter candle surface became discoloured and, compared to the Unit A cleaning procedure, was a much more arduous task. However, the flow rate returned to about 90% of original capacity after each cleaning cycle. The brush method was less abrasive to the ceramic and the candle diameter was reduced much less than for the Unit A_B control filter candle during the 40-day test.

(c) Unit C

The cartridges in these units are not meant to be cleaned and are designed to be discarded after 1000 U.S. gallons (3800 L) have been processed or when the flow rate reduces to an impractically low level.

(d) Unit D pocket filters

The two pocket filters were cleaned only once during the test at day 34 after the appearance of coliforms in the first unit. The same brushing procedure was used as for the Unit B filters.

Calibration of Feed Pumps

The Neptune proportioning pumps used to deliver the bacterial challenge into the influent test water stream were calibrated to deliver the correct dosage in relation to the flow of water through each manifold. No attempt was made to adjust the delivery of the bacteria when flow rates to the manifolds varied; this was not considered to be a serious source of variation in the influent bacterial counts.

Timing Cycles

The three Unit B filters (rated at 2.5 L/min) and the control were run 4 min "on", 16 min "off" for a maximum possible flow of 19 200 L in 40 days, which is the equivalent of 12 L/day for 4.4 years. The expected lifetime of the units is 6-7 years under normal use.

The total capacity of Unit C is only 3800 L; therefore only about 95 L/day could be processed to span the 40-day test period. Flow in these units (and the control) was regulated to 1 L/min in a 16-hour, 2 min "on" 18 min "off" cycle. This is equivalent to about 316 days of use at 12 L/day.

The two Unit D pocket filters were tested in the 40-day trial using challenge water obtained from the manifold system. A volume of 600 mL was pumped through each unit each day for 40 days.

Flow Measurements

Flow measurements were made daily. From these measurements it was quickly determined that the Unit B filters and Unit A_B control should be cleaned each day when operated on a 20% "on"/80% "off" duty cycle if flow rates were to be maintained at approximately 2.5 L/min.

The Unit C filters are throw-away cartridge type units and cannot be cleaned. The cartridge is designed to be changed when flow is too low or after 3800 L (1000 U.S. gal.). These units were adjusted to a flow rate of 1 L/min using a needle throttle valve. The Unit A_C control was set to 1 L/min with the valve and the ceramic cartridge was cleaned when the flow dropped below the level of 250 mL/min.

Test Organisms

Fresh domestic sewage was obtained from a sewage pumping station on the premises of the Ontario Research Foundation, (Sheridan Park Research Community, Mississauga). As described previously, the sewage was filtered through glass wool, then a stock culture prepared by seeding 60 L of dechlorinated tap water so that, when injected and diluted in the manifold system, the bacterial challenge received by test filters would include approximately 1000 to 5000 total coliforms per 100 mL.

Parameter	ORF Tap Water		Low TDS* Water		High TDS * Water	
	#1	#2	Run 1	Run 2	Run 1	Run 2
Total dissolved solids mg/L	217	198	122	92	520	500
Total organic carbon mg/L	4.5	4.0	2.5	3.0	4.0	3.5
Total inorganic carbon mg/L	27	27	16	15	62	64
Chloride (Cl ⁻) mg/L	31	30	19	15	84	84
Sulphate (SO ₄ ⁻⁻) mg/L	32	27	17	12	151	80
Ammonia-N mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Alkalinity } mg/L as	93	90	45	44	157	232
Total Hardness } CaCO ₃	13	150	74	82	150	240
pH	6.7	6.7	6.2	6.2	8.4	8.4
Turbidity NTU	ND**	ND	ND	ND	34	1.3
Temperature	5.5	4.5	21	20	23	22

* TDS Total Dissolved Solids

** ND None Detected

Test Waters - Chemical Composition

An analysis was made of the three types of water used in the study. Samples for analysis were taken from the manifold and included the bacterial challenge.

Low TDS water was obtained as previously described; about 450 L seeded with bacterial challenge were prepared and pumped through the system using the "normal" time cycle. The high TDS water was prepared by spiking with salts as before together with sodium bicarbonate, this time bringing the TDS content to about 500 mg/L.

Microbiological Analyses

(a) Sample Collection and Neutralization

These procedures were conducted according to the methods described in Part I.

(b) Coliform Enumeration

The standard total coliform membrane filter procedure was employed as before, 100 mL aliquots of the effluents being examined for coliforms. Verification of atypical colonies was carried out by transferring doubtful colonies to tubes of lauryl tryptose broth, followed by transfer of positives to brilliant green lactose bile broth. Gas formation in the confirmatory medium within 48 hours of incubation at 35°C was deemed as evidence for the presence of coliform organisms.

(c) Standard Plate Counts

Standard plate count procedures as given in "Standard Methods for the Examination of Water and Wastewater"(3) were employed. For volumes greater than 10 mL, a membrane filter technique was used. Incubation was carried out at 35°C for 48 hours and the counts recorded as colony forming units per millilitre.

Measurement of Silver Concentrations in Water Samples

Silver was determined by atomic absorption spectrophotometry according to details given in Part I.

Test Protocol

The test protocol described in Part I of this report was used as the basis for testing the in-line filters (B and C). The portable units (D) were tested daily as described earlier in this section (Timing Cycles).

RESULTS AND DISCUSSION

Filter Performance

(a) Bacterial Counts

Bacterial challenge was maintained to each of the units for the 40-day test period. The three Unit B filters completely removed or inactivated coliform organism (Table 6) throughout the test period even with the final high challenge of 200 000 coliforms/100 mL. The effluent from the Unit A_B control was similarly coliform-free. Standard plate counts were maintained at a low level throughout the test, usually below 500/mL with the 3 Unit B filters and below 125/mL in most cases with the control Unit A_B.

The Unit C filters did not prevent coliform survival from the influent waters. Even in the first day (Table 7), all three samples failed in the dynamic mode. The cartridge on Unit C-III was replaced on day 11 but within 8 days, the coliform counts were again near the influent level. Similarly, the standard plate counts were extremely high, all being overgrown (i.e., >3000/mL). The coliform counts on the Unit A_C control on days three and five were not considered significant. These positive samples were due to splashing from the effluent of Unit C filters which were passing coliforms. A splash guard was put up to prevent cross-contamination and this prevented recurrence of the problem.

The Unit D portable devices were tested manually over a 38-day period (Table 8). One unit produced coliform-free water for 19 and the other for 22 days. Standard plate counts followed the same trend. After this point one device did not remove coliform organism and the other produced variable quality water.

(b) Silver Levels

The silver levels in effluents from Units B (Table 9) were measured periodically throughout the period of the test; levels were generally well below the 50 µg/L limit specified in the Guidelines for Canadian Drinking Water Quality - 1978 (2). Silver concentrations in the effluent from control Unit A_B were also consistently below 50 µg/L.

In the Unit C filters no silver was found in any of the effluents, (Table 10) indicating that this was not a silver-containing and releasing unit. In the control, values on days 5 and 14 exceeded 50 µg/L, perhaps due to the fact that flow rates were well below those under which this type of unit is designed to operate.

The portable filters (Unit D) released mean levels of 43 and 37 $\mu\text{g/L}$ silver over the 38 days of the test. The highest recorded values for Units D-I and D-II, respectively, were 136 and 81 $\mu\text{g/L}$.

(c) Volume of Water Processed Before Failure

The flow characteristics of Units A_B and B when operated on a cycle of 4 minutes "on", 16 minutes "off" for 16 hrs. per day, are shown in Figure 3. Because of the rapid clogging, they were required to be cleaned once per day.

The three Unit B filters processed an average of 196 L/day for an average of 7853 L in 40 days. The control processed 225 L/day for 9000 L in 40 days. No coliforms were found in either of these tests.

The Unit C filters processed 1 L/min during the "on" period but all three units failed before 100 L were processed. The replacement filter installed on Unit C-III on day 11, also failed before 100 L were processed.

The portable Unit D filters were tested by pumping 60 mL/day through the units. The first device failed after processing between 17 and 18 L of challenge water and the second device failed after processing 22 L; it did resume producing coliform-free water for 8 days before again showing breakthrough.

CONCLUSIONS AND RECOMMENDATIONS

The use of filtration is one of the classic methods to eliminate bacteria from water. Filtration media may be relatively effective in removing bacteria by acting as "depth filters" but eventually bacteria may colonize the filter media as they become nutrient-rich due to concentration of materials from the water passing through them; eventually breakthrough of the bacteria will occur. This is the reason that most devices of this type incorporate a bacteriostatic agent such as silver in the filter. The silver acts to prevent most bacteria from replicating in the filter and to some extent, prevents back-contamination of the water from the effluent side.

In addition to the normal, dechlorinated tap water, tests with modified water quality were performed at approximately 10% and 100% of the life of the filter. In these tests low total dissolved solids (TDS) and high TDS were used. The low TDS water represents the "worst case" for possible excess silver dissolution and the high TDS, high pH water tends to decrease silver dissolution and thus provides the "worst case" condition for bacterial overgrowth in the filters.

Data presented in Parts I and II of this report show that the two devices utilizing ceramic filters impregnated with metallic silver (Units A and B), do an adequate job of removing coliform and total plate count bacteria at their rated flows under accelerated lifetime testing conditions. Both the portable units which employ the same principle failed early in the tests. The failure was not due to any apparent cracking or discontinuity in the ceramic candle, so it must be assumed that improper sealing by the washer might have allowed some water to bypass the filter.

The device (Unit C) which employs only activated carbon, yet is claimed to remove bacteria from water, presents a special problem. This unit has been tested by others (unpublished study commissioned by the manufacturer) by subjection to discrete, high level challenges; a test was performed three times during the lifetime of the unit, water free of challenge organisms being passed through the unit between each test. On this basis a reduction in bacterial counts from approximately 2.7×10^8 to below 1 E. coli cell/L was claimed. In the present study, where the challenge was continuous, the unit failed within one day with all 4 filters tested. While the filter may remove most bacteria when 1 L of sample is poured in and the effluent is collected, it cannot support a continuous challenge for any extended length of time.

The results obtained here support the need for stringent laboratory testing of all types of water treatment devices likely to be used by the consumer. Tests such as those described here and elsewhere(1) can help to ensure that good, potable water will be produced from units available to the consumer. Examinations of water filters, however, usually involve only tests for bacterial removal properties and, because of the high costs involved, fail to address the question of virus removal from water. Since viruses are extremely small (20-250 nm), they would not be expected to be removed from water except when they are bound on particulates or bind on the filters themselves. Little study has been made of this problem, although it is well established that a high fraction of virus is particle-bound. Because these units are designed to be used with raw water where adsorptive surfaces are abundant, and because it is not recommended that they be used in water polluted to an extent greater than about 1000 total coliforms or 100 fecal coliforms per 100 mL, it is considered that the virus hazard is probably not excessive.

REFERENCES

1. Environmental Health Directorate. 1977. Survey and test protocols for point-of-use water purifiers. Health and Welfare Canada, Publication 77-EHD-8, Ottawa.
2. Health and Welfare Canada. 1979. Guidelines for Canadian Drinking Water Quality - 1978. Canadian Government Publishing Centre, Supply and Services Canada, Hull, Quebec.
3. American Public Health Association. 1976. Standard Methods for the Examination of Water and Wastewater. 14th Ed. American Public Health Association, New York.

Table 1

Calibration of Feed Pumps

	Pump Setting	Volume in mL/min Delivered against zero head
Pump A	0	105
	20	112.5
	40	120
	60	127.5
	80	137.5
	100	140
Pump B	0	95
	20	107.5
	40	117
	60	127.5
	80	138
	100	145

Table 2

Coliform and Standard Plate Counts on Input Water and Effluent From Filters

"E" Series - E. coli Challenge "S" Series - Sewage Challenge

Day	Total coliform/100 mL				SPC/mL				Total coliform/100 mL				SPC/mL				Static (St) or Dynamic (Dy)
	Input 1	E ₁	E ₂	E ₃	Input 1	E ₁	E ₂	E ₃	Input 2	S ₁	S ₂	S ₃	Input 2	S ₁	S ₂	S ₃	
Pre-conditioning tap water only	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	Dy
1	ND	ND	ND	ND	ND	ND	ND	ND	8	ND	ND	ND	2.1	ND	ND	ND	Dy
2	ND	ND	ND	ND	ND	ND	ND	ND	800	ND	ND	ND	>650	ND	ND	ND	St
3	ND	ND	ND	ND	ND	ND	ND	ND	2 000	ND	ND	ND	163	ND	ND	ND	St
4	30 000	ND	ND	ND	300	1.5	0.07	1.5	26 000	ND	ND	ND	>650	0.05	0.06	0.08	Dy
5	1 400	-	-	-	20	-	-	-	300	-	-	-	26	-	-	-	Dy
6	2 300	ND	ND	ND	27	0.01	ND	0.08	200	ND	ND	ND	24	ND	ND	ND	St
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
8	1 400	ND	ND	ND	18	0.02	ND	ND	3 800	ND	ND	ND	>650	ND	0.01	0.03	Dy
9	10 000	ND	ND	ND	105	ND	ND	0.01	7 500	ND	ND	ND	300	0.04	ND	ND	Dy
10 Low TDS	2 000	ND	ND	ND*	21	ND	ND	0.11	1 800	ND	ND	ND*	75	ND	ND	0.33	St
11	2 000	ND	ND	ND	23	ND	ND	ND	4 300	ND	ND	ND	>650	ND	ND	ND	Dy
12 High TDS	4 600	ND	ND	ND	52	0.05	ND	0.75	2 000	ND	ND	ND	>650	1.5	1.5	5	St
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
14	11 700	ND	ND	ND	130	ND	1.0	1.4	17 000	ND	ND	ND	>650	0.05	0.02	0.2	Dy
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
16	16 300	ND	ND	ND	>650	0.35	0.8	3	8 000	ND	ND	ND*	>650	0.11	0.9	2.5	Dy
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
18	8 000	ND	ND	ND*	97	spr	spr	spr	8 000	ND	ND*	ND*	>650	spr	spr	spr	St
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
20	1 000	ND	ND	ND	40	1.3	0.8	2.0	6 500	ND	ND	ND	400	2.0	0.3	0.12	St
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
22	1 300	ND	ND	ND	18	1.0	1.2	1.0	1 800	ND	ND	ND*	800	1.0	1.0	1.1	Dy
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
24	11 000	ND	ND	ND	>650	0.01	ND	ND	1 600	ND	ND	ND	3 000	ND	ND	ND	Dy
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
26	2 000	ND	ND	ND	26	0.8	2.0	3.0	3 800	ND	ND	ND	200	2.0	3.0	3.0	St
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
28	10 000	ND	ND	ND	>650	spr	spr	3.0	25 000	ND	ND	ND	1 000	spr	3.0	2.0	St
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
30	1 300	ND	ND	ND	30	0.1	0.17	0.05	2 300	ND	ND	ND	130	3.0	0.1	0.06	Dy
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
33	2 000	ND	ND	ND	36	0.25	0.48	spr	2 700	ND	ND	ND	200	3.0	spr	spr	St
34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Dy
35	2 800	ND	ND	ND	370	ND	2.0	2.0	2 700	ND	ND	ND	137	3.0	2.5	3.5	St
36	8 000	ND	ND	ND	80	0.3	0.6	0.8	10 000	ND	ND	ND	>650	3.5	spr	spr	Dy
37	3 000	ND	ND	ND	80	1	23	8	1 500	ND	ND	ND	87	2	ND	ND	St
38 Low TDS	1 000	ND	ND	ND	65	130	170	300	1 700	ND	ND	ND	57	300+	300+	300+	St
39 High TDS	1 400	ND	ND	ND	37	130	97	150	1 800	ND	ND	ND	>650	300+	300+	300+	St
40	400 000	ND	ND	ND	12 000	40	15	300+	400 000	ND	ND	1	13 000	97	21	270	Dy

ND = none detected

ND* = non detected but some non-sheen colonies on Endo medium

spr = spreader

Table 3

Silver (Ag+) Levels in µg/L in Input Water and Filter Effluent Streams

"E" Series - E. coli challenge.

"S" Series - sewage challenge.

Day	Input 1	E1	E2	E3	Input 2	S1	S2	S3	Static (St) or Dynamic (Dy)
Start	<1	32	22	16	<1	36	23	22	St (after 56 hours standing)
3		-	-	-	<1	39	13	30	St (after 8 hours standing)
4		8	9	17		16	9	7	Dy
6		36	22	22		7	11	8	St (after 8 hours standing)
8		6	7	4	<1	7	8	9	Dy
10	<1	45	26	30	<1	37	35	34	St (after 16 hours standing Low TDS)
12		31	22	24		26	22	22	St (after 16 hours standing High TDS)
14		11	13	10		11	11	14	Dy
16		9	10	23		13	10	13	Dy
18		16	13	14		17	13	13	St (after 8 hours standing)
20		20	20	19		28	19	17	St (after 8 hours standing)
22		9	8	7		8	8	7	Dy
24		7	7	4		6	6	5	Dy
26		18	16	16		19	21	14	St (after 8 hours standing)
28		14	14	12		13	13	14	St (after 8 hours standing)
30	<1	6	8	4	<1	6	8	6	Dy
33	<1	9	9	13	<1	8	9	9	Dy
35	<1	18	18	16	<1	19	19	16	St (after 8 hours standing)
36		10	11	9		19	10	11	Dy
37		14	15	13		16	15	13	St (after 8 hours standing)
38		76	53	42		47	69	53	St (after 16 hours standing Low TDS)
39		55	36	39		33	42	42	St (after 16 hours standing High TDS)
40	<1	36	24	26	<1	22	22	23	St (after 8 hours standing)

Table 4

Silver Levels in $\mu\text{g/L}$ in Filter Effluent Streams

"E" series - E. coli challenge

"S" series - sewage challenge

E ₁	E ₂	E ₃	S ₁	S ₂	S ₃	Static (St) or Dynamic (Dy)
12	11	7	8	10	9	D (Low TDS)
24	26	20	21	26	22	S (After 16 hours standing Low TDS)
30	14	17	-	-	-	S (After 10 hours standing Low TDS)

Table 5

Daily and Cumulative Water Flow Through Test Filters

"E" Series - E. coli challenge "S" Series - sewage challenge

Days from start	E ₁ L/day	Cumulative total L	E ₂ L/day	Cumulative total L	E ₃ L/day	Cumulative total L	S ₁ L/day	Cumulative total L	S ₂ L/day	Cumulative total L	S ₃ L/day	Cumulative total L	Filters cleaned
0	420	420	320	320	460	460	420	420	420	420	400	400	
1	256	676	120	440	312	772	164	584	100	520	120	520	
2	236	912	80	520	256	1028	120	704	80	600	80	600	
3	140	1052	50	570	160	1188	80	784	56	656	52	652	
4	84	1136	40	610	92	1280	48	832	30	686	32	684	
5	460	1596	300	910	420	1700	391	1223	500	1186	400	1084	X
6	360	1956	270	1180	400	2100	360	1583	326	1512	340	1424	
7	290	2246	220	1400	318	2418	260	1843	243	1755	252	1676	
8	220	2466	170	1570	236	2654	160	2003	160	1915	164	1840	
9*	94	2560	76	1646	100	2754	70	2073	69	1984	72	1912	
10	150	2710	128	1774	164	2918	112	2185	112	2096	112	2024	
11*	58	2768	48	1822	62	2980	40	2225	42	2138	43	2067	
12	440	3208	390	2212	444	3424	472	2697	384	2522	420	2487	X
13	340	3548	272	2484	338	3762	340	3037	276	2798	320	2807	
14	240	3788	154	2638	232	3994	208	3245	168	2966	220	3027	
15	172	3960	108	2746	156	4150	144	3389	108	3074	126	3153	
16	106	4066	76	2822	100	4250	73	3462	64	3138	76	3229	
17	72	4138	52	2874	72	4322	56	3518	54	3192	58	3287	
18	420	4558	288	3162	440	4762	444	3962	380	3572	400	3687	X
19	344	4902	220	3382	340	5102	328	4290	298	3870	320	4007	
20	248	5150	160	3542	236	5338	232	4522	204	4074	234	4241	
21	136	5258	90	3632	126	5464	118	4640	118	4192	118	4359	
22	72	5358	46	3678	58	5522	56	4696	56	4248	56	4415	
23	492	5850	312	3990	468	5990	496	5192	410	4658	428	4843	X
24	340	6190	220	4210	332	6322	320	5512	268	4926	292	5135	
25	140	6330	96	4306	136	6458	140	5652	126	5052	120	5255	
26	96	6426	68	4374	80	6538	88	5732	80	5132	80	5335	
27	76	6502	60	4434	68	6606	68	5800	70	5202	60	5395	
28	40	6542	30	4404	30	6636	36	5836	34	5236	36	5431	
29	420	6962	280	4744	424	7060	444	6280	376	5612	390	5821	X
30	240	7202	168	4912	240	7300	238	6518	216	5828	220	6041	
31	106	7308	74	4986	98	7398	94	6612	94	5922	86	6127	
32	62	7320	48	5034	54	7452	50	6662	52	5974	50	6177	
33	390	7760	280	5314	420	7872	450	7112	364	6338	380	6557	X
34	372	8132	216	5530	296	8168	318	7430	250	6588	240	6797	
35	110	8242	84	5614	116	8284	100	7530	116	6704	80	6877	
36	60	8302	48	5662	60	8344	52	7582	60	6764	44	6921	
37*	215	8517	140	5802	220	8564	230	7812	200	6964	200	7121	X
38*	187	8704	165	5967	170	8734	176	7988	150	7114	162	7283	
39	270	8974	170	6137	240	8987	244	8232	210	7324	240	7523	
40	115	9089	76	6213	100	9074	86	8318	80	7404	86	7609	

* 8-hr day run only on Low and High TDS and 16-hour rest period

Table 6

Unit B Tests Biological Data

Challenge to test units			Effluent from test units							
DAY Static/ Dynamic	Total Coli- forms/ 100 mL	Standard Plate Counts/ mL	Total Coliforms/100 mL				Standard Plate Counts/mL			
			Control Unit A _B	B-I	B-II	B-III	Control Unit A _B	B-I	B-II	B-III
0 Dy	Before Seeding	Before Seeding	ND	ND	ND	ND	ND	ND	ND	ND
1 Dy	5 000	OG	ND	ND	ND	ND	.07	.05	.02	.02
3 Dy	4 000	-	ND	ND	ND	ND		ND	.02	.12
5 Dy	7 000	90	ND	ND	ND	ND	.01	.21	.01	ND
7 St	6 000	130	ND	ND	ND	ND	.05	.80	.80	1.3
9 Dy	8 000	-	ND	ND	ND	ND	.60	.90	.83	1.1
10 St	6 400	-	ND	ND	ND	ND	.40	1.2	.90	1.3
11 Dy	6 200	150	ND	ND	ND	ND	.07	OG	OG	OG
12 St	2 500	300	ND	ND	ND	ND	.65	180	200	150
14 St	4 400	-	ND	ND	ND	ND	ND	103	83	70
16 Dy	3 700	720	ND	ND	ND	ND	21	400	600	530
19 St	4 400	470	ND	ND	ND	ND	.60	80	83	76
22 Dy	4 000	730	ND	ND	ND	ND	1.6	OG	OG	OG
24 Dy	3 500	200	ND	ND	ND	ND	ND	10	40	70
27 St	2 700	870	ND	ND	ND	ND	14	930	440	370
29 Dy	4 000	1 470	ND	ND	ND	ND	OG	870	530	490
31 St	3 800	830	ND	ND	ND	ND	111	820	350	360
33 Dy	4 100	950	ND	ND	ND	ND	120	840	360	350
34 Dy	4 700	-	ND	ND	ND	ND	-	-	-	-
35 St	3 400	85	ND	ND	ND	ND	1	8	1	3
36 Dy	3 200	97	ND	ND	ND	ND	ND	60	40	80
37 St	11 800	850	ND	ND	ND	ND	1	5	6	30
38 St	2 300	1 370	ND	ND	ND	ND	89	40	59	82
40 Dy	200 000	6 000	ND	ND	ND	ND	104	320	614	1020

ND - None Detected

- - Not Done

OG - Overgrown at 1×10^{-1} dilution

Dy - Dynamic

St - Static

Table 7
Unit C Tests Biological Data

Challenge to test units			Effluent from test units							
DAY Static/ Dynamic	Total Coli- forms/ 100 mL	Standard Plate Counts/ mL	Total Coliforms/100 mL				Standard Plate Counts/mL			
			Control Unit A _C	C-I	C-II	C-III	Control Unit A _C	C-I	C-II	C-III
0 Dy	Before Seeding	Before Seeding	ND	ND	ND	ND	ND	ND	ND	ND
1 Dy	5 000	-	ND	OG	OG	OG	.04	OG	OG	OG
3 Dy	4 000	-	2*	OG	OG	OG	.04	OG	OG	OG
5 Dy	6 000	75	5*	4 000	4 700	4 300	.63	65	90	69
7 St	6 000	130	ND	1 400	5 600	800	.13	OG	OG	OG
9 Dy	8 000	-	ND	1 500	2 000	1 200	OG	OG	OG	OG
10 St	6 400	-	ND	7 300	6 000	4 000	OG	OG	OG	OG
11 Dy	6 200	150	ND	65	50	ND**	1.8	OG	OG	.25**
12 St	2 500	300	ND	20	18	23	OG	OG	OG	OG
14 St	4 400	-	ND	OG	OG	87	ND	OG	OG	OG
16 Dy	3 700	720	ND	5 300	4 000	150	140	OG	OG	900
19 St	4 400	470	ND	7 500	8 000	4 800	OG	OG	OG	28
22 Dy	4 000	730	ND	-	-	-	OG	-	-	-
24 Dy	3 500	200	ND	-	-	-	470	-	-	-
27 St	2 700	870	ND	-	-	-	1 260	-	-	-
29 Dy	4 000	1 470	ND	-	-	-	1 470	-	-	-
31 St	3 800	830	ND	-	-	-	OG	-	-	-
33 Dy	4 100	950	ND	-	-	-	-	-	-	-
34 Dy	4 700	-	ND	-	-	-	-	-	-	-
35 St	3 400	85	ND	-	-	-	5	-	-	-
36 Dy	3 200	97	ND	-	-	-	-	-	-	-
37 St	11 800	850	ND	-	-	-	41	-	-	-
38 St	2 300	1 370	ND	-	-	-	-	-	-	-
40 Dy	200 000	6 000	ND	-	-	-	-	-	-	-

Dy - Dynamic
St - Static
OG - Overgrown at 1×10^{-1} dilution
- - Not Done

* - Suspected cross-contamination
from splashing from Unit C
effluents
** - New filter cartridge fitted
to Unit C-111

Table 8

Unit D Portable Filters

CHALLENGE					Unit D-I				Unit D-II		
Day	Volume Pro- cessed Litres	Total Coli- forms/ 100 mL Influent	Stan- dard Plate Count per mL Influent		Silver µg/L	Total Coli- forms/ 100 mL Effluent	Stan- dard Plate Count per mL Effluent		Silver µg/L	Total Coli- forms/ 100 mL Effluent	Stan- dard Plate Count per mL Effluent
0	.6	ND	ND		30	ND	ND		37	ND	ND
3	1.8	4 000	-		-	ND	-		-	ND	-
5	3.0	7 000	90		27	ND	ND		34	ND	ND
9	5.4	8 000	-	LTDS	136	ND	-	LTDS	81	ND	-
11	6.6	6 200	150	HTDS	69	ND	4	HTDS	64	ND	2
19	11.4	4 000	470		53	ND	>100		22	ND	>100
22	13.2	4 000	730		22	100	>100		25	ND	>100
24	14.4	3 500	200		20	160	400		24	7*	600
27	16.2	2 700	870		-	ND	ND		-	ND	ND
29	17.4	4 000	1 470		29	33*	150		31	ND	130
31	18.6	3 800	830		-	26	1 300		-	ND	280
34	20.4	4 700	-		24	47	-		26	ND	-
35	21.0	3 400	85	LTDS	21	17	96	LTDS	24	ND	110
37	22.2	11 800	850	HTDS	66	59	6	HTDS	55	5	96
38	22.8	2 300	1 370		18	14	140		18	2	85

LTDS - Low Total Dissolved Solids

HTDS - High Total Dissolved Solids

* - Atypical colonies which did not confirm as coliforms

ND - None Detected

- - Not Done

Table 9

Unit B Tests Silver Data

Day	Conditions	Silver levels in filter effluents (ug/L)			
		Control Unit A _B	B-I	B-II	B-III
0	Dy	7	16	15	17
1	Dy	5	14	14	14
3	Dy	8	10	11	12
5	Dy	16	21	23	11
7	St	9	46	30	28
8	St	27	11	14	16
9	LTDS Dy	10	5	7	7
10	LTDS St	7	1	1	1
11	HTDS Dy	10	6	7	9
12	HTDS St	15	10	13	15
14	St	49	6	6	8
16	Dy	4	2	2	2
19	St	42	5	7	8
22	Dy	23	15	17	14
24	Dy	13	2	2	2
27	St	18	10	9	11
29	Dy	4	1	1	2
33	Dy	1	1	1	1
34	LTDS Dy	8	2	2	3
35	LTDS St	12	9	7	10
36	HTDS Dy	6	5	5	5
37	HTDS St	12	20	17	18
40	HC Dy	2	2	1	2
60*	St	35	30	25	45

Dy - Dynamic St - Static
 HTDS - High Total Dissolved Solids
 LTDS - Low Total Dissolved Solids
 HC - High Challenge
 * - 20-day Stagnation Period from conclusion of 40-day test

Table 10

Unit C Tests Silver Data

Day	Conditions	Silver levels in filter effluents (µg/L)			
		Control Unit A _C	C-I	C-II	C-III
0	Dy	5	2	<1	<1
1	Dy	12	<1	<1	<1
3	Dy	7	<1	<1	<1
5	Dy	109	1	<1	1
7	St	37	1	1	1
8	St	25	1	1	1
9	LTDS Dy	7	1	<1	2
10	LTDS St	21	1	1	1
11	HTDS Dy	19	1	1	1
12	HTDS St	15	1	1	1
14	St	88			
16	Dy	7			
19	St	26			
22	Dy	18			
24	Dy	29			
27	St	11			
29	Dy	1			
33	Dy	1			
38		5			

Dy - Dynamic

St - Static

HTDS - High Total Dissolved Solids

LTDS - Low Total Dissolved Solids

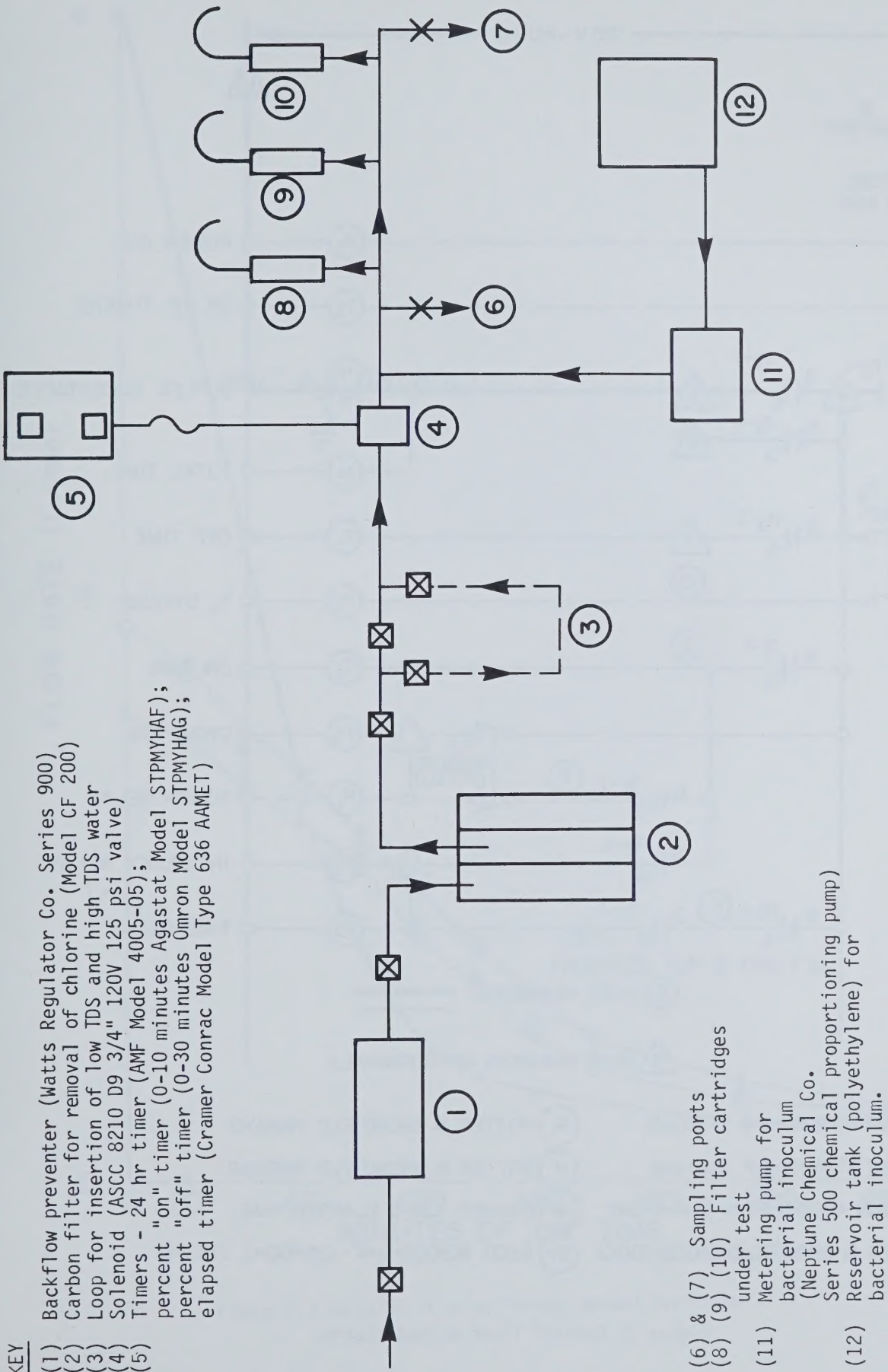
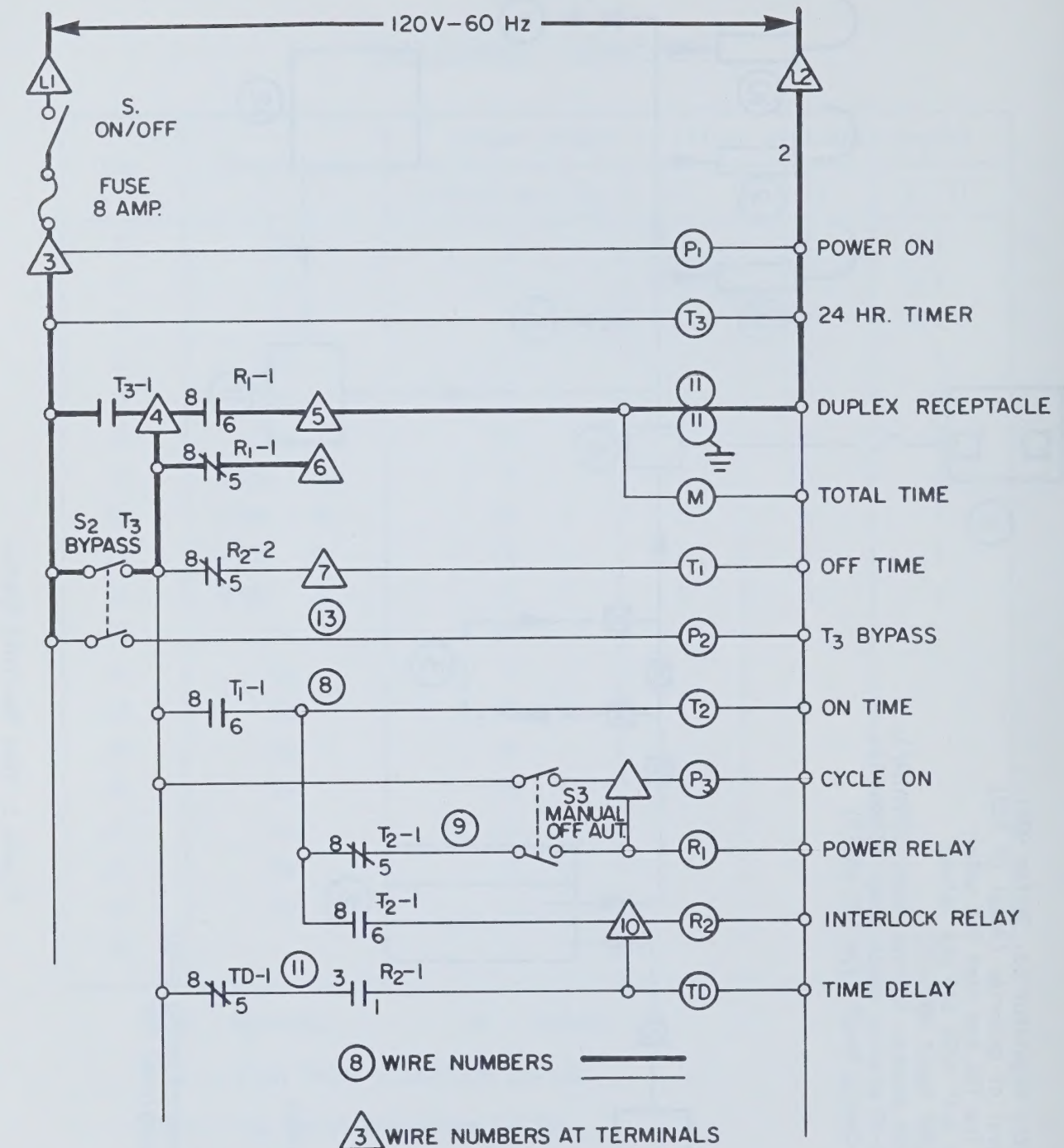


Figure 1 Test Manifold System



- | | |
|---|---|
| (T ₁) AGASTAT STPMYH-A-G 0-30 min | (R) POTTER & BROMFIELD PRNAYO |
| (T) AGASTAT STPMYH-A-F 0-10 min | (R) POTTER & BROMFIELD KRPNAG |
| (T) PARAGON 4003-5 24 hr SKIP-A-DAY | (M) CRAMER 636-5 ELAPSED TIME |
| (TD) POTTER & BROMFIELD CH338-7000I | (SV) ASCO 8210D9-3/4"-125V60HZ. 125 PSI |

Figure 2 Control Timer Wiring Diagram

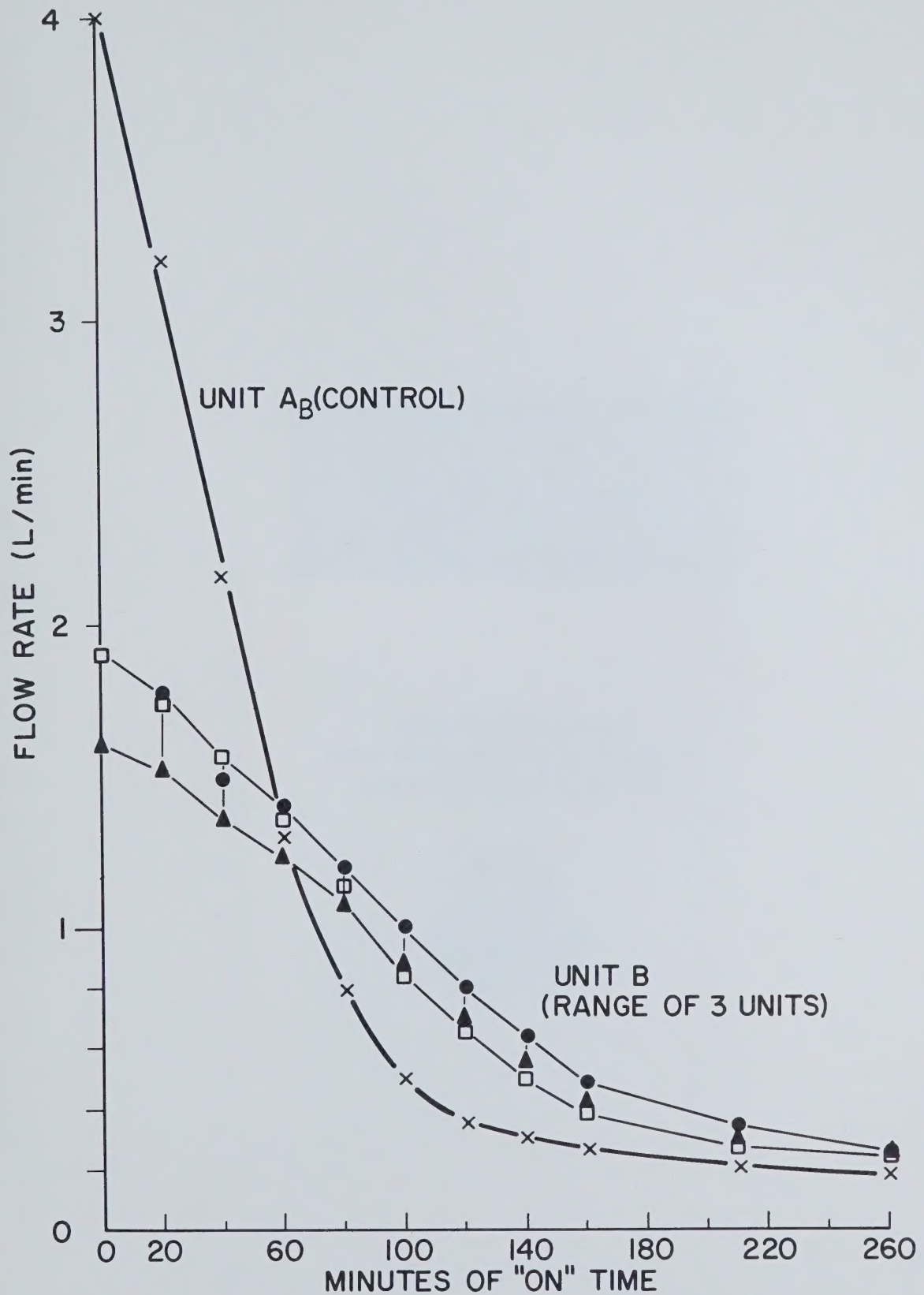


Figure 3 Flow Rates of Water Through Ceramic Cartridges

CA1 HW 1180E54

Canada. DNH. EHD.

80-EHD-54

ASSESSING THE EFFECTIVENESS OF SMALL FILTRATION
FOR THE REMOVAL OF HAZARDOUS SUBSTANCES FROM DRINKING WATER

**RESOURCE CENTRE
INST. FOR ENVIRON'L STUDIES
UNIVERSITY OF TORONTO**



